# NATIONAL BUREAU OF STANDARDS REPORT

10 581

Progress Report

on

**INTERMEDIARY BASE
AND CEMENTATION**

<NBS>

# U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
[2] Part of the Center for Radiation Research.
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# NATIONAL BUREAU OF STANDARDS REPORT

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on

## INTERMEDIARY BASE
## AND CEMENTATION

by

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# U.S. DEPARTMENT OF COMMERCE

## NATIONAL BUREAU OF STANDARDS

## Intermediary Base

An intermediary base is that portion of a restoration placed: 1) directly between the dentin and the final restorative material, or 2) interposed between a therapeutic material for pulp treatment and the restorative material. Ideally, the intermediary base replaces some of the dentin lost by caries, trauma or cavity preparation.

Selection of a material for use as an intermediary base is dependent on the amount and condition of the remaining tissues as well as the intended purpose of the base. Table 1 lists the materials currently available. Some of the brands* in the various classes are: Zinc phosphate cement (ZP) "Tenacin"[†]; zinc oxide-eugenol cement (ZOE); modified zinc oxide-eugenol, e.g. o-ethoxybenzoic acid (EBA) "EBAC"[††], aluminum oxide ($Al_2O_3$) "Opotow EBA with alumina"[†††] and poly(methylmethacrylate) (PMMA) "T & B"[‡]; calcium hydroxide ($Ca(OH)_2$) "Hydrex"[‡‡] and zinc polycarboxylate or zinc polyacrylate (PC) "Durelon".[‡‡‡]

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[†] Tenacin: L. D. Caulk Co., Milford, Del.

[††] EBAC: The Lorvic Corp., St. Louis, Mo.

[†††] Opotow EBA with alumina: Opotow Dental Mfg. Corp., Brooklyn, N.Y.

[‡] T & B: L. D. Caulk Co., Milford, Del.

[‡‡] Hydrex: Kerr Manufacturing Co., Detroit, Mich.

[‡‡‡] Durelon: Premier Dental Products Co., Philadelphia, Pa.

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* Certain commercial materials and equipment are identified in this paper in order to specify adequately the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards nor does it imply that the material or equipment identified is necessarily the best available for this purpose.

## Condition of remaining tooth tissue

Dental caries and attrition gradually expose dentin tubules, allowing the natural defensive mechanisms of the tooth to form reparative and sclerotic dentin.[1,2] This is contrasted with operative procedures and trauma which immediately expose unaltered dentin tubular contents to destructive forces such as heat, dehydration and chemicals. Generally, 2.0 mm of remaining unaltered dentin between the floor of the cavity and the pulp provides an adequate insulating barrier against irritating components of restorative materials.[3]

It is impossible to determine remaining dentin thickness during a cavity preparation. Pulp tissue may be irritated through open tubules of viable dentin. Damage may also occur through an undetected exposure. Ischemia produced by the epinephrine in the anesthetic often restricts bleeding so that a small exposure is not noticed.

## Functions of an intermediary base

The functions of an intermediary base are: (1) insulation from chemical and thermal shock; (2) strength to resist the forces transmitted toward the pulp by compaction of filling materials or compression of cementing media; and (3) modification of the internal walls of cavity preparations. Some authors[4] include insulation against electric shock as a function but cements are seldom used to alleviate this problem.

Chemical and physical properties

Table 1 and Figure 1 present the various materials and a comparison of essential properties.

Chemical irritation by the intermediary base or final restorative material should be avoided, or kept to a minumum, since the pulp has recently been weakened by the carious process or operative procedure. The initial contact of the base material with the dentin produces the greatest irritation and injury to the pulp.

All of the materials given in Table 1 provide insulation against temperature change. Voth[5] observed that a layer 1.4 mm thick of $Ca(OH)_2$, ZOE or ZP was an effective barrier against both heat and cold but that a thin film was of no value. He did not determine the optimum thickness; however, 0.5 mm is accepted as a minimum to prevent discomfort caused by thermal changes.

In addition to chemical irritation of the pulp a chemical reaction of the base with the final restorative material must be avoided. Any material which hardens by free radical polymerization should not contact eugenol-containing bases because the eugenol inhibits the polymerization. This is true for acrylic resins, some composite filling materials and rubber base impression materials. Two thin coats of varnish placed over the cement are usually sufficient to control this polymerization inhibition.

The highest compressive stress is usually exerted during compaction of the dental amalgam or gold restoration and is within the first 3 - 8 minutes after mixing.[6] Early and ultimate compressive strengths are included in Table 1. Thickness of the intermediary base to disseminate compressive forces is also important. It has been shown[7] that 1 mm thick bases made of materials exceeding 14 kg/cm$^2$ (200 psi) will not crumble or be displaced by usual condensing forces. Since there is sufficient space in deep cavities, it is better to err on the side of using an excess of the material.

## Modifying internal cavity walls

Another function of a base material, modifying internal walls of cavity preparations, is required for indirect restorations, i.e., those completed outside the mouth to be cemented in place. Properly selecting and using material for this function reduces the amount of tooth structure to be removed and assists in the retention of the restoration. Selection of a material for this base need not be limited to the usual cements but can include dental amalgam and gold. Retention of the final restoration will be improved when parallelism can be achieved without removing excessive amounts of tooth structure.

## Radiopacity

Since they are completely covered by the permanent restorations, intermediary bases cannot be identified by visual examination. To facilitate subsequent interpretation of x-rays in diagnosis of recurrent caries the intermediary base should be radiopaque. The relative radiopacity of various materials is shown in Figure 1.

## Mixing

Mixing base materials is in reality one of the final steps in the manufacture of the cement. The ingredients should be carefully formulated and packaged by the manufacturer after exhaustive experimentation and testing. Carefully worded and illustrated instructions for each product are generally included in the package to insure obtaining the optimum physical properties. Consequently, detailed mixing instructions have been omitted in this discussion of the various classes of materials. The only way to assure success is to follow the instructions provided with each package. As one paint manufacturer so aptly stated on the label of his product, "If you don't intend to follow our instructions, don't use our paint".

Several brands of intermediary base materials are being
packaged in preproportioned capsules for mixing in mechanical
devices. No results have been reported of tests made using
this technique. However, from experience with similar packaging
for silicate cements and dental amalgam, the resultant products
should be highly satisfactory.

### Zinc phosphate cement

Zinc phosphate (ZP) cement continues to be the standard
used for the evaluation of all new dental cements. The powder
for this cement contains approximately 9 parts calcined zinc
oxide to 1 part magnesium oxide.[8] When this powder is mixed
with the liquid containing phosphoric acid buffered with salts
of aluminum or zinc, the compounds formed are phosphates of
zinc, magnesium and aluminum. The outer layers of the
particles react to form a phosphate matrix that surrounds the
unreacted cores of the larger particles. The proportion of
powder particles and matrix varies with the amount of powder
incorporated into a given amount of liquid. As the powder
particle content increases in proportion to the matrix, better
physical property values are obtained.

The liquid is a precisely balanced phosphoric acid and
water solution. The water content is sensitive to the room
atmosphere. In conditions of high humidity the phosphoric
acid takes on additional water and in dry conditions gives off

water. Either condition disturbs the setting reaction, con-
sequently the liquid bottle should be open just long enough
to remove the needed amount. This should be done immediately
prior to mixing to protect the liquid on the mixing slab.

In the past few years a ZP cement has been introduced
using water as the liquid which replaces the unstable phos-
phoric acid. The resultant cements when compared to acid
liquid ZP have greater film thickness, less strength, higher
solubility and are equally irritating to the pulp tissue.[9]

Both of these cements, acid and water settable, are
irritating to the pulp tissue. However, placing an underlay
of two thin coats of varnish or a base of either $Ca(OH)_2$ or
ZOE will prevent this irritation. ZP cement has a high crush-
ing strength, both early and late,[4,10] Table 1, it is radiopaque,
Figure 1, and its thermal insulation is effective even in thin
layers.

Zinc phosphate cement is mixed on a cool, clean and dry
glass slab. The powder is separated in small units so that
a little powder is incorporated at a time. The mixture is
spread with heavy pressure on a flexible steel spatula so the
heat of the reaction will dissipate into the glass. Most
manufacturers recommend $1\frac{1}{2}$ minutes to complete the mix. As
stated earlier the amount of powder controls the physical
properties, more powder gives higher strength and lower solubility
than when less powder is used.

## Zinc oxide-eugenol cements

In the 1960's considerable research and development attention was focused on ZOE cements. The favorable response by the pulp to this material stimulated interest in improving physical properties such as crushing strength, solubility and film thickness for cementation procedures.[11,12] Table 2 presents representative products as they evolved from the addition of zinc acetate to hasten the set to the most recent additive, polycarbonate, which contributes strength and abrasive resistance. The products, with $Al_2O_3$, Figure 2, and PMMA develop early crushing strengths much in excess of the minimum 200 psi required to resist the forces used in compacting amalgam and direct gold, Table 1.[4,10] Virmani reports that two modified ZOE cements, B & T and Temrex*, along with the ZP material Tenacin, have sufficient early strength to resist forces necessary to place gold foil, mat gold or powdered gold.

Pulpal tissue response to ZOE with additives (EBA, hydrogenated rosin, $Al_2O_3$ or PMMA) is similar to the original ZOE.[13,14]

Zinc oxide-eugenol cements are mixed as prescribed by each manufacturer by spatulating to wet the powder particles and to develop the consistency desired by the operator. The mixing procedure does not have as critical an effect on the

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* Temrex: Interstate Dental Co., New York

physical properties as does the mixing of ZP, but again strength and solubility are improved as the powder concentration increases. Moisture accelerates the setting reaction consequently working and setting times can be modified by carefully controlling the moisture content. A few drops of glacial acetic acid in the bottle of eugenol also accelerates the set.

These cements are radiopaque, Figure 1, and can be used safely in deep cavities without danger to the pulp. The development of secondary dentin, when actual exposures are covered with ZOE with or without additives, has not been as consistent as with $Ca(OH)_2$. Therefore, when close to the pulp tissue and there may be an undetected pulp exposure, use of these cements is not the treatment of choice. In such circumstances use of $Ca(OH)_2$ is indicated.[15-20]

## Calcium hydroxide cements

Calcium hydroxide, $Ca(OH)_2$, when mixed with distilled water is an effective agent for the treatment of exposed pulp tissue. Unfortunately the resulting product has no strength. There are several commercial mixtures containing $Ca(OH)_2$, e.g., Dycal* and Hydrex, which, when hardened, have sufficient early crushing strength to withstand compaction forces required for amalgam but not direct gold, Table 1.[4,10] These also permit

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* Dycal: L. D. Caulk Co., Milford, Del.

resolution of mild inflammation of the pulp and the formation of reparative dentin. These materials are used mainly in deep cavities for their therapeutic effect on the pulp and remaining dentin. When they are placed on dry dentin they flow freely filling the deepest portions, thus ensuring complete adaptation. Moisture accelerates the set and interferes with coverage of the dentin wall. $Ca(OH)_2$ is not radiopaque therefore the commercial products add varying amounts of a radiopaque material, Figure 1.

Thanik[21] reported that with less than 0.1 mm of dentin $Ca(OH)_2$ is the least irritating base material, with ZOE next and ZP the most irritating. To avoid pulp displacement in deep cavities, $Ca(OH)_2$ should be carefully placed over the dentin in the pulpal or axial walls for there may be an undetected pulp exposure. Sufficient bulk must be provided so the combined dentin and intermediary base will withstand compaction forces.

These $Ca(OH)_2$ bases are the material of choice under some composite and resin restorations for there is no eugenol to interfere with polymerization hardening. Berk[19] demonstrated that these materials protect the pulp against irritation by silicate and ZP cements. They are equally effective in protecting the pulp under composite restoratives.

## Polycarboxylate cements

The relatively recently developed polycarboxylate
cement (PC) is a mixture of a modified zinc oxide powder and
polyacrylate acid liquid.[22]  Durelon, Poly-C,* Zopac,** and
PCA*** are representative products currently on the market.
The results of several studies[22-24] show adhesion by Durelon
to enamel and to a lesser extent to dentin.  This adhesive
action to tooth structure is of interest in its potential use
as an intermediary base to modify the contour of tooth prepara-
tions.  It can be painted on undercut areas then, upon hardening,
the crown or inlay preparation can be completed.  Its early
strength is not known; however, the 24 hour strength,[24] Table 1,
should be adequate to help protect a thin dentin wall against
hydrostatic forces present during cementation of precision
castings.  It is radiopaque, Figure 1, and is less irritating
to pulp tissue than zinc phosphate cement,[22-24] indicating a
potentially promising material.  The extremely critical method
for handling to obtain maximum adhesion is discussed later in
the cementation section.

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## Summary

As Manley[1] stated, "The respect the operator shows for
the dentin is directly reflected in the health of the pulp."
To aid dentists in showing this respect for the dentin there
is a wide range of materials available to use as an inter-
mediary base. Choice should be determined by the role the
operator wants the material to fill, e.g., strength (ZP),
non-irritating (ZOE, modified ZOE, or $Ca(OH)_2$), adhesive
(PC) and radiopaque (all the zinc cements and others with
radiopaquing added). Frequently a combination of materials
is desirable, such as $Ca(OH)_2$ to permit formation of a dentin
bridge followed by either ZOE with EBA and $Al_2O_3$ or ZP. Some
commercial preparations of $Ca(OH)_2$, such as Dycal and Hydrex,
have sufficient strength to be used alone under dental amalgam
compaction.

EBA, alumina and hydrogenated rosin in ZOE have improved
the early strength and solubility so these cements can be
placed on freshly-cut dentin with confidence that
there will be no pulp irritation and that the cement will
withstand compaction forces. They can be used as a temporary
restoration and the deeper portion retained as an intermediary
base when the final preparation is completed at a subsequent
appointment. Studies concerning the response of the pulp

tissue to all the modified ZOE cements indicate that they
retain the "kind-to-the-pulp" characteristic of ZOE.

As newer materials and modifications of old ones are
brought on the market, they should first be evaluated for
pulp tissue response.  This is true of any product even
though it may be only slightly varied in formulation from
an already cleared product.[25]

## Table 1

### Intermediary Base

| | Material | Compressive Strength | | | | Pulp Response ** |
|---|---|---|---|---|---|---|
| | | Early 7 min | | Ultimate 24 hr | | |
| | | kg/cm² | psi | kg/cm² | psi | |
| Zinc phosphate | Acid | 77 | 1100 (4)* | 1190 | 16900 (4) | ++++ (21) |
| | Water settable | n o t available | | 673 | 9550 (9) | ++++ (9) |
| Zinc oxide-eugenol | Zinc acetate | 40 | 600 (4) | 88 | 1250 (4) | ++ (15,20,21) |
| | EBA & Al₂O₃ | 400 | 6000 (11) (ten min) | 900 | 13000 (11) (one week) | ++ (13,14) |
| | PMMA | 60 | 900 (4) | 140 | 2000 (4) | ++ (13) |
| | Cavetec | 30 | 400 (4) | 53 | 750 (4) | ++ (4) |
| Calcium hydroxide | H₂O | 0 | 0 | 0 | 0 | - (15,20,21) |
| | Dycal | 77 | 1100 (4) | 77 | 1100 (4) | - (4) |
| | Hydrex | 35 | 500 (4) | 100 | 1400 (4) | - (16) |
| Poly-carboxy-late | | n o t available | | 350 | 5000 (24) | +++ (24) |

$$*$$ Figures in parentheses represent reference

** Pulp response
   a. Exposure
      Dentin bridge        -

   b. Dentin unbroken
      Mild inflammation     ++
      Moderate inflammation   +++
      Severe inflammation     ++++

Table 2

ZINC OXIDE-EUGENOL CEMENTS

| Composition | | Commercial Products |
|---|---|---|
| Powder | Liquid | |
| ZnO<br>Hydrogenated rosin<br>Zn acetate | Eug. | Intermediary bases<br>Temporary restorations<br>Periodontal packs<br>Root canal sealers |
| ZnO<br>Hydrogenated rosin | EBA<br>Eug. | Opotow EBA<br>ProCem<br>Ultim EBA<br>EBAC |
| ZnO<br>$Al_2O_3$<br>Hydrogenated rosin | Eug.<br>EBA | Opotow EBA with alumina<br>ProCem with alumina |
| ZnO<br>PMMA | Eug.<br>Acetic<br>acid | Fynal<br>IRM<br>T & B<br>Opotow temporary |
| ZnO<br>Polystyrene | Eug. + ? | Kalzinol |
| ZnO<br>Polycarbonate | Eug. + ? | Decigenol |
| ZnO<br>Polymerized resin<br><br>Carnaba wax<br>Zn acetate | Eug.<br>Mineral<br>oil | Cavitec (ingredients<br>blended in two tubes) |
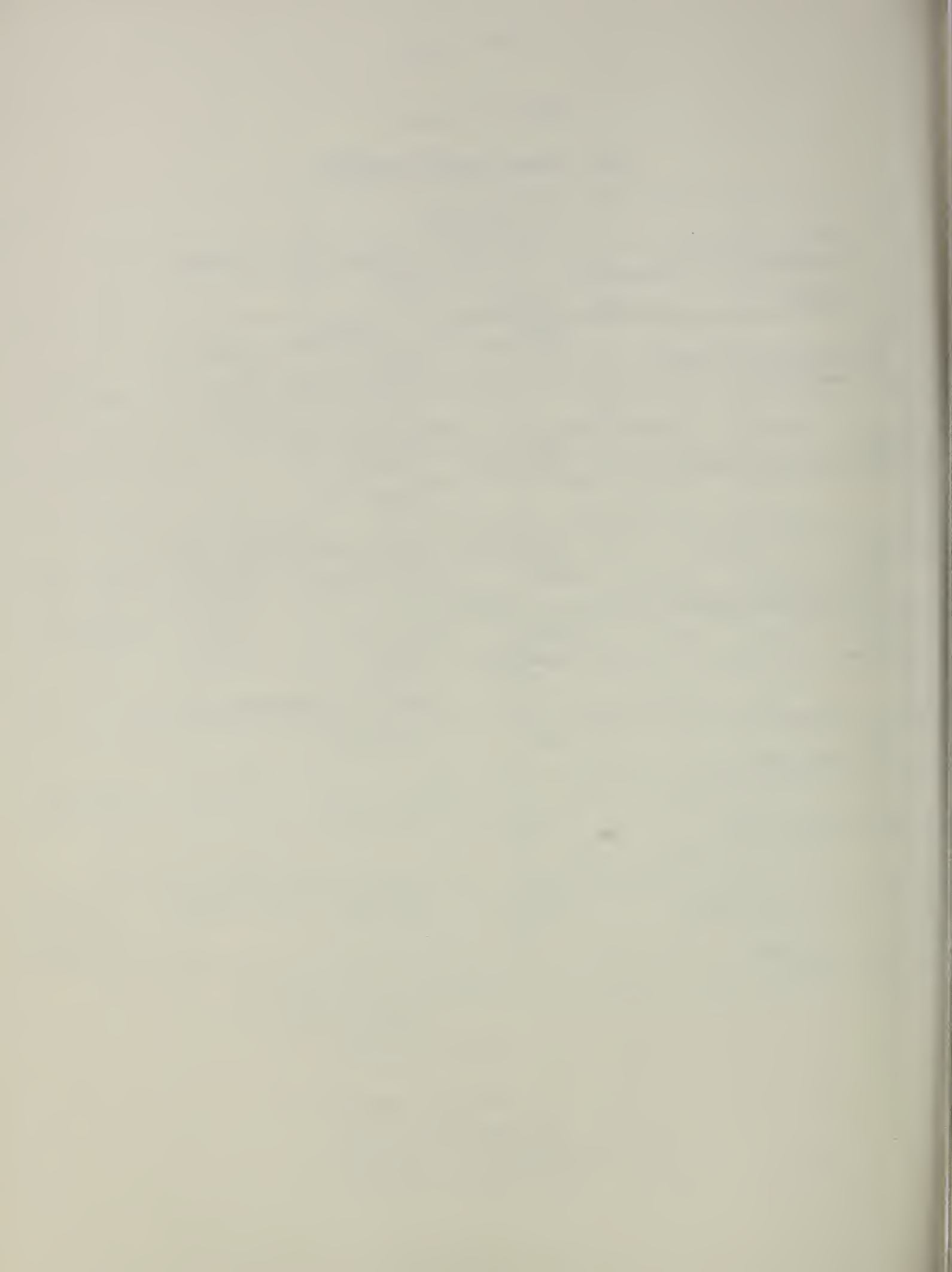
# Cementation

The term cementation is used to describe the process
of using a soft substance which, when hardened, holds a
dental restorative appliance to oral structures or to
another dental appliance.  Currently, retention of the
dental restorative appliance is dependent on mechanical,
not adhesive or bonding, factors.  Some laboratory studies
appear promising in the quest for such a bonding agent as
active research studies continue.

Included in the physical properties responsible for
mechanical retention are: 1) crushing strength; 2) ability
to wet the surfaces of the tooth and restoration; 3) resis-
tance to solubility and disintegration in the oral environ-
ment; and 4) film thickness.  Among many additional factors
affecting retention are: 1) total area of the axial walls;
2) degree of parallelism of two opposing axial walls of the
preparation, e.g., mesial vs. distal or buccal vs. lingual;
3) accuracy of fit of the restoration; and 4) direction of
forces of occlusion in relation to the path of insertion of
the restoration or appliance.

The criteria for selecting a cementing medium are
based on these physical properties and the biological
response of the pulp tissue to the cement.  The manner
of handling also has a bearing on selection since ease of
manipulation is extremely important in a clinical environment.

The operator has some control over each of the above
factors by his design of the various tooth preparations
and by selecting the correct cement and manipulating it
properly.  This discussion is limited to the selection
and handling of the materials.  Crushing strengths of
cement, as Worner[26] described so well, are a measure of
their cementing properties.  He said, "The ability of
these materials to hold restorations in position appears
to be due to the fact that  the finely divided particles
of cement fill small irregularities in the surfaces and
lock the metal in place.  To remove requires a fracture
of these irregular extensions (exceeding the crushing or
shear strength of the material)."

Jorgensen[27] presented a comprehensive analysis of
various operator controlled factors which affect film
thickness.  He states that the more viscous the cement,
the more difficult it is to seat the restoration completely.
Viscosity is dependent on the type of cement, the powder-
liquid ratio, duration of mixing time and the temperature.
Once the cement is mixed and placed on the materials to
be cemented the viscosity has been established.  The amount
and method of applying the positioning force then becomes
the principal factor controlling the residual film thickness
at the tooth-restoration interface.  The operator should

apply a steady 10 pound force[27] until the cement has
hardened.  A small dab of wet cement on an adjacent tooth
provides a good test sample.  An additional element con-
tributing to film thickness, which the operator controls,
is venting.  In this way the hydrostatic pressure is re-
leased as the fluid cement escapes.  An accurately fitting
casting placed in or on a tooth preparation with a minimum
of film thickness takes full advantage of both the frictional
resistance and the cement's compressive strength.

The American Dental Association Specification No. 8
for dental zinc phosphate cement[8] defines the limits of
certain physical properties, Table 3.  Two types of cement,
based on powder particle size, are specified.  The manufac-
turer should print on the package which Type, I or II, of
Specification No. 8 that the cement is guaranteed to meet.
Maximum film thickness permitted for Type I is 25 micro-
meters μm (0.001 in.).  Type II may have a film thickness
up to 40 μm (0.0016 in.).  Type I is designed to permit
seating of precision castings.  Type II is suitable for
all other uses.  These specified physical properties are
also used as a standard for comparison of the other classes
of cementing materials as listed on Table 3.  Manufacturers
that claim comparable cementation film thickness for their

materials should state in their directions the powder
to liquid ratio that will meet the Type I specification.

## Zinc Phosphate Cement

Zinc phosphate cement, ZP, Type I, Tenacin, Fleck's*
etc., for cementation continues to be the standard for
comparison of other materials being developed for luting
precision castings. Although ZP is irritating to the pulp
tissue a liner of varnish (two thin layers) or a base of
either $Ca(OH)_2$ or ZOE, covering unaltered dentin effectively
protects the pulp. A thin but complete layer of varnish
does not reduce the retentive strength of ZP.[28] Additives
to the phosphoric acid liquid, such as eugenol, are not
effective in reducing pulpal irritation. If in the event
of a weakened pulp the sedative effect of zinc oxide-
eugenol is desired, temporary cementation with one of the
ZOE cements is recommended. Permanent cementation with ZP
can be delayed until resolution of the hyperemia is complete.

Type I powder is used for cementing precision dental
castings. The liquid is handled and mixing is completed
as described in the section on intermediary bases. To obtain
the cementation consistency the amount of powder incorporated
into the liquid is reduced.

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* Fleck's: Mizzy, Inc., Clifton Forge, Va.

Should additional working time be required the mixing slab is cooled to just above the dew point. If too cold, water will condense on the slab and be incorporated in the mix and interfere with the hardening reaction.

Another recommended method of prolonging the set is to spatulate a "pinhead" of powder into the liquid and let stand two to three minutes before mixing. This is not as consistent or precise as controlling the mixing slab temperature, but in some situations may be the method of choice. This technique cannot be employed in areas of high humidity because the liquid is hygroscopic and must be dispensed immediately before mixing to prevent upsetting the acid-water balance of the liquid component.

As stated earlier the greater the amount of powder in a given quantity of liquid within the limits of the system the better are the physical properties.[29] Therefore, careful mixing is important to: 1) increase the strength; 2) reduce solubility; and 3) provide a consistency which permits seating a precision casting,[27] Table 3. Careful mixing means using a cooled slab, incorporation of small increments, thoroughly wetting each particle of powder before adding more, using heavy pressure on a flexible spatula, spreading the mix over a large area of the slab and using the full time prescribed by the manufacturer to complete the mix. This is one and a half minutes for most brands.

Water settable zinc phosphate cements are inferior
to the conventional ZP cements and should not be used,
Table 3.[30],[9]

## Polycarboxylate cement

The polycarboxylate cements, (PC), Durelon, Poly-C,
Zopac and PCA have been introduced for the express purpose
of cementing stainless steel to enamel.[22]  This cement is
formed by mixing zinc oxide powder with polyacrylic acid
liquid.  Smith[22] claims that while the carboxyl bonds are
still available immediately after mixing, they form a bond
with the calcium ions in the tooth, thus effecting true
adhesion to the enamel and to a lesser extent to dentin.[22]
Etching or other pretreatment of the enamel surface does not
change the bond strength.[31]  Thermal cycling apparently has
no effect on strengths evaluated by static fatigue, dynamic
fatigue and peal bond tests.[22]  Water uptake and solubility
are quite high in laboratory testing, indicating that con-
siderable long term clinical testing is required before
routine use can be recommended.

Strict observance of the mixing instructions is neces-
sary to obtain the maximum properties of the polycarboxylate
cements.  The powder to liquid proportion for cementation
should be between $1\frac{1}{2}$ to $2\frac{1}{2}$ parts of powder to one part liquid
by weight.

The desired consistency should be developed through trial
and error. Once the proportions are determined mixing can
be completed by bringing all the powder into the liquid and
spatulating quickly. The cement should be completed in less
than 30 seconds and in contact with the restoration and tooth
immediately thereafter. Correct powder to liquid ratio and
prompt usage, well before the gloss disappears, develops the
strongest adhesive and physical properties. Operators who
have used this cement are enthusiastic over the lack of
discomfort experienced by the patient during the seating of
the restorations.

Although polycarboxylate cements were specifically
formulated for cementation of stainless steel orthodontic
appliances to enamel, tests have been made on retention of
gold cast crowns on teeth prepared with a 10° taper.[32]
Results have also been reported of laboratory testing of
retention of gold castings in Class I cavities prepared in
recently extracted teeth.[24] A comparable force was required
in both experiments to remove crowns cemented with zinc phos-
phate and polycarboxylate. ZOE with polymer had about one
half the retentive strength of PC. These laboratory tests
do not indicate a superiority over ZP for cementing gold crowns.
Instability of this cement in water, high uptake and solubility,[23]

indicates potential risks in its routine use. Preliminary reports, however, are very favorable from dentists who are meticulous in following the recommended handling technique.

### Modified zinc oxide-eugenol and EBA cements

The modified zinc oxide-eugenol and EBA cements, discussed in the Intermediary Base section, are mixed to cementing consistency and used as luting agents for precision castings. Some have physical properties, as indicated on Table 3,[12,33] comparable to ZP and viscosity and wetting properties which are easier than ZP to use in seating precision castings. These new EBA, $Al_2O_3$ filled cements continue to have the original ZOE pulp protective and sedative characteristics.[13,1]

In light of these favorable qualities these cements are growing in popularity as luting agents. The EBA cements with $Al_2O_3$ have compressive strengths and retention values similar to ZP, Table 3, but are somewhat higher in their solubility values.[12]

Solubility and disintegration data are based on the specification test[3] that measures the residue after 24 hours. Another aspect of disintegration related to solubility but not determined by the 24 hour residue is the loss of eugenol as shown by Wilson and Batchelor.[34] These investigators claim that aqueous leaching of eugenol from ZOE cement

(unmodified) is continuous as the cement matrix hydrolyzes to eugenol and zinc hydroxide. Thus, the cement in 20 weeks time loses mechanical strength and disintegrates. This long-term process is not evident in the 24 hour specification test.

As with ZP, mixing for intermediary base and cementation differ only in the proportion of powder added to a given amount of liquid.

Well controlled long-term clinical studies of cementation with modified ZOE or EBA have not been reported. Two progress reports[35,36] have indicated favorable results over a short period of time. However, other operators are observing failures after one year, especially in those cases involving bridge abutments or short crown teeth. Consequently, until long-term (3 years or more) well controlled studies are reported these modified ZOE cements are not recommended for general use in cementation of fixed prostheses.

### Silicophosphate cement

Silicophosphate cements such as Kryptex*, Lucent** and the recently introduced Fluorthin* might be termed hybrid cements for the powder is a mechanical mixture of about 9 parts silicate and 1 part zinc phosphate cement.[29] Since the

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* Kryptex, Fluorothin: S. S. White Mfg. Co., Philadelphia, Pa.
** Lucent: L. D. Caulk Co., Milford, Del.

liquid is similar to that for ZP the same handling precautions are necessary.

The compressive strength of these products is superior to ZP while the solubility is inferior,[37,38] Table 3. The fluoride which is a basic ingredient of the silicate portion, is gradually leached out and may increase the resistance of the adjacent enamel to solubility in mouth fluids.[39] Along with these qualities the ability to retain or hold crowns and castings is almost as strong as ZP.[28] The manipulative characteristics, viscosity and film thickness, however, make it difficult to seat accurately fitting castings. One brand, Fluorothin, meets the film thickness specification of 25 μm for Type I cement. A favorable feature is the silicate-like translucency which blends well esthetically with porcelain and acrylic restorations. Consequently, this class of cement is used principally for their esthetic value in cementing crowns and porcelain inlays.

## Acrylic resin cements

The physical properties, esthetic qualities and manipulative characteristics of acrylic cements such as Justi Resin Cement* are similar to the direct filling acrylic resins. Solubility,

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* Justi Resin Cement: H. D. Justi, Philadelphia, Pa.

which is near zero, and surface wettability are two
properties which are superior to ZP.  This surface wettability,
or adaptation, makes it seem as though a bonding reaction
has occurred.  The apparent bonding is lost, however, as the
cement absorbs water and the cement-tooth interface becomes wet.

The acrylic resins are mixed by blending carefully
measured quantities of powder and liquid.  Unless otherwise
specified, the desired portion of powder is placed in a mound
on a paper mixing pad.  A flexible stainless steel spatula is
used to make a crater in the powder and the corresponding pro-
portion of the viscous liquid is dropped into the crater.
After letting the liquid soak into the powder for a few seconds
it is rapidly mixed, using approximately 1 square inch of the
mixing area, to a homogenous mass.  The total elapsed time from
adding the liquid to the completion of mix should be less than
30 seconds.  Immediately after cementation the excess material
must be removed from the tooth, restoration and spatula, for
any that is permitted to set is most difficult to remove.
The resin cements contribute to the desirable esthetic qualities
of porcelain inlays, thus they, like silicophosphate cements,
are used principally for their favorable appearance.

## Polyurethane

In recent years polyurethanes have attracted much attention as potential adhesive liners and tissue sealants. These materials are still in the experimental stage but appear promising.

The isocyanates used in urethane formulations act as water scavengers, reacting with residual water on the tooth surface to form carbamate intermediates. The carbamate intermediate immediately decomposes to amines that in turn react with excess isocyanate groups to yield a substituted urea, polyurethane. Eventually, as the tooth surface is dried the polyurethane is crosslinked. Urethanes can be formulated to yield elastic films that appear suitable for use as adhesive liners between dentin or enamel and conventional and composite resins and amalgam restorations.

A modified polyurethane has been used to cement restorations to teeth without undercutting or removing an excessive amount of tooth tissue.[41] The bonding of acrylic restorations was improved by adding a coupling agent to the urethane. Etching the enamel with citric or formic acids before applying the urethane further increased the retention of the acrylic restorations.

Temporary cementation of completed restorations

Two of the factors controlling the choice of a material for temporary cementation are: 1) the need for a sedative material and 2) the compressive strength required for retention of the temporary coverage. Temporary cements vary from a sedative ZOE that can be prepared with varying compressive strengths to the high compressive strength of ZP that is irritating to the pulp tissue.

Zinc oxide-eugenol cements can make a hypersensitive tooth less sensitive and more receptive to subsequent permanent cementation. Recently cut, non-sensitive dentin remains comfortable when sealed against oral fluids. Either ZOE or ZP will maintain a marginal seal if formulated with the appropriate compressive strength to maintain the retention of the restoration. Both Horn[34] and Gilson[42] discuss selecting temporary cements according to compressive strengths. An accurately fitting restoration is almost self retaining; however, a suitable material is needed to develop the marginal seal.

Horn[34] gives the following directions for preparing a non-setting ZOE. Trial mixes should be made of a commercial ZOE with varying amounts of silicone grease (Dow Corning 3 compound* or R. M. Silicone grease**) and about 1% methyl or

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* Dow Corning, Midland, Michigan
** Rocky Mountain Products, Denver, Colorado

propyl parapen to establish the appropriate consistency to permit seating a single or multiple casting. The parapen additive contributes to the plasticity of the mix and is said to increase the bacteriostatic or fungistatic capability of the cement. This non-setting material maintains the marginal seal and will not require undue force to remove the restoration when ready for further treatment.

As the accuracy of fit or the self-retaining capacity of the temporary coverage is reduced, a more adhesive, stronger temporary cementation material is needed. This can be made by mixing varying amounts of petrolatum with ZOE. An ill-fitting temporary crown may need the strength of a strong cement, preferably ZP. In these cases varnish is used to protect the pulp and the temporary crown can be cut off so that chance of damage to the preparation during removal is reduced.

Table 3

Physical Properties of Various Materials Mixed to Cementing Consistency

| Material | Time of Setting | Compressive strength 24 hr | | Film thickness | Solubility and Disintegration (by weight) | Diametral tensile strength 24 hr | | Relative retention ZP = 100 |
|---|---|---|---|---|---|---|---|---|
| | min | kg/cm² | psi | μm | % | kg/cm² | psi | |
| ADA Spec. #8 Type I (cementing) (8) | 5 min. 9 max. | No specification | | 25 maximum | 0.2 maximum | No specification | | No specification |
| ZnPO₄ acid | 5.5 | 700 | 9956 | 18 (28) | 0.2 (12) | 820 | 12300 (4) | 100 (28) |
| ZnPO₄ water settable | 8.5 | 1050 (12) | 15000 | 75 (9) | 0.4 (9) | Not available | | Not available |
| ZoE + EBA and alumina | 9.5 (12) | 630 (30) | 9000 | 26 (12) | 0.05 (12) | 49 | 700 (33) | 100 (28) |
| ZoE + polymer | 6-10 (33) | 955 (12) | 14000 | 32 (4) | 0.08 (33) | 70 (33) | 1000 | 55 (28) |
| Silicophosphate | 3½-4 (37) | 490 (33) | 7000 | 42 (38) | 0.4 (37) | Not available | | 80 (28) |
| Resin cement | 4-10 (40) | 2800* (37) | 29500* | 10-60 (48) | 0.0-0.4 (40) | Not available | | Not available |
| Polycarboxylate | 7.5 (24) | 670** (40) | 9500** | 21 (24) | 0.6 (23) | 55 (23) | 800 | 100 (24) |
| | | 320 (24) | 4600 | | | | | |

\* 7 days
\*\* 1 hour

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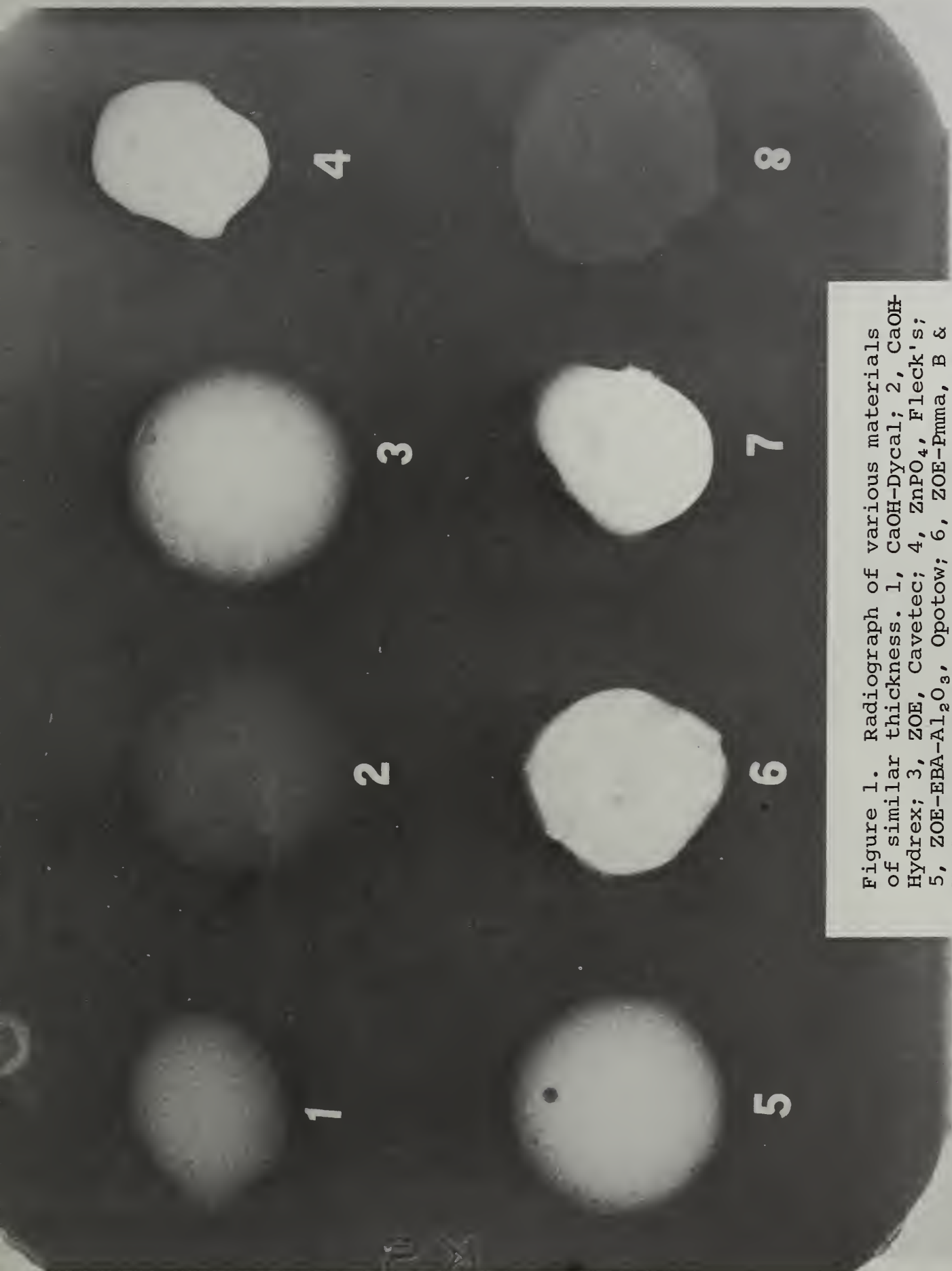     49:14-20, Jan-Feb 1970.
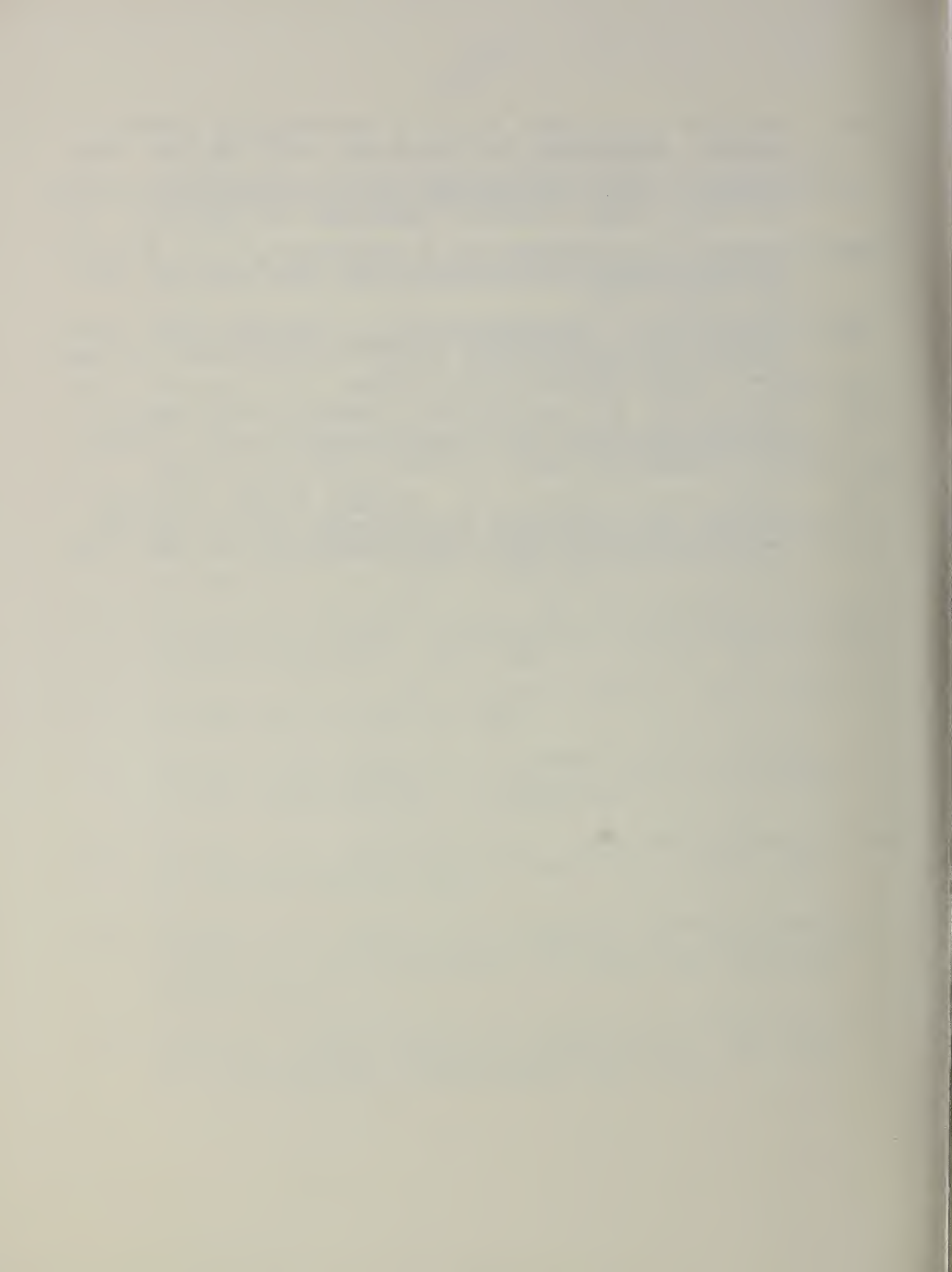
Figure 1. Radiograph of various materials of similar thickness. 1, CaOH-Dycal; 2, CaOH-Hydrex; 3, ZOE, Cavetec; 4, ZnPO$_4$, Fleck's; 5, ZOE-EBA-Al$_2$O$_3$, Opotow; 6, ZOE-Pmma, B & T; 7, ZPA, Durelon; 8, Composite, Adaptic.
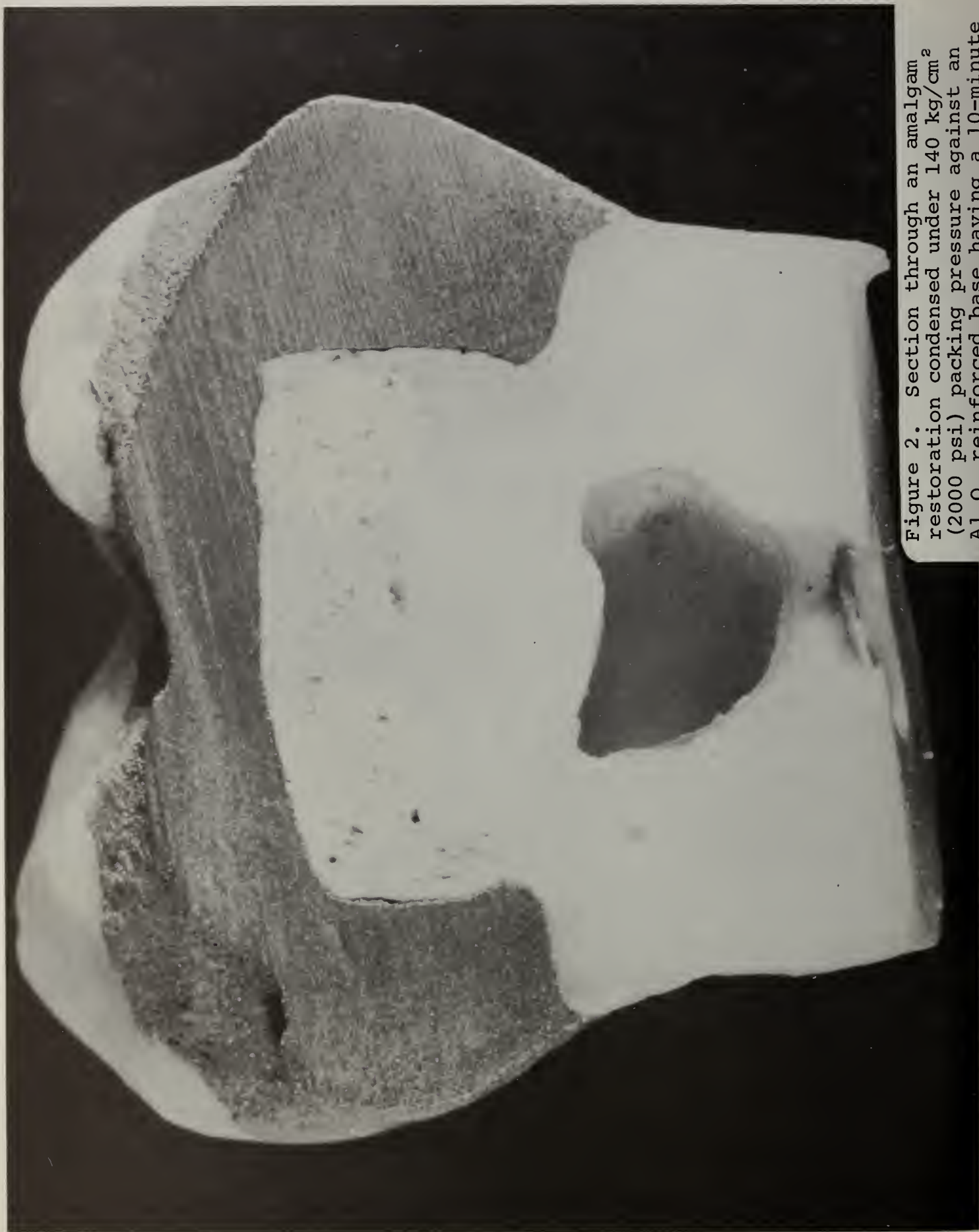
Figure 2. Section through an amalgam restoration condensed under 140 kg/cm² (2000 psi) packing pressure against an Al₂O₃ reinforced base having a 10-minute compressive strength of 450 kg/cm² (6000 psi).

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